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14. ABSTRACT
The research program commenced 1 April 1998 and terminated 31 October 2000. Progress was achieved in a broad range of areas, including (1) Optimization of simulations, (2) Models for design of video-on-demand systems, (3) A fault tolerant Condor-PVM mixed integer program solver, (4) Gamma Knife radiosurgery, (5) Asymptotics and confidence regions for stochastic variational inequalities, (6) GAMS-MATLAB interface, (7) Modeling language/CONDOR interface, (8) Stochastic effects in the NPS-RAND Mobility Optimizer (NRMO). This progress is described in more detail in Section 3. This work was described and documented in a total of 34 research papers. These papers, with their status as of the end of the reporting period, are listed in Section 5.

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Planning, Optimization, Stochastic Optimization

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This is the final progress report on AFOSR Grant F49620-98-1-0417 to the University of Wisconsin-Madison. The principal investigators (PI) were Michael C. Ferris and Stephen M. Robinson, and the period of performance was 1 April 1998 – 31 October 2000.

1. Objectives

The objectives of the research effort have not changed from those stated in the proposal. The principal research tasks are summarized here for later reference:

1. Combining sample-path optimization with deterministic optimization and equilibrium models
2. Obtaining gradients from simulation codes using automatic differentiation
3. Developing effective confidence-region methodology for sample-path techniques
4. Generating guidance systems that are flexible and robust, allowing for uncertain future events
5. Developing improved methods for model adaptation (learning), taking into account changes both in data and in model structure
6. Developing a system for quick reallocation of large amounts of computing power in a manner that is transparent to the user, within a working prototype system

2. Status of Effort

The research program commenced 1 April 1998 and terminated 31 October 2000. Progress was made in several areas, described in more detail in Section 3. This work was described and documented in a total of 34 research papers. These papers, with their status as of the end of the reporting period, are listed in Section 5.

3. Accomplishments/New Findings

As is detailed in Section 5, work under this grant resulted in the production of 34 papers and technical reports. In this section we describe several of the most important areas of work that produced those papers, indicating the progress achieved and the papers resulting from that progress.

3.1. Optimization of Simulations

We have developed a mechanism that allows certain parameters of existing (black-box) simulations to be optimized via commercial solvers. The optimization problem is written in a modeling language with a simulation module accessed using an external function call. Since we allow no changes to the simulation code at all, we use a quadratic approximation of the simulation function to obtain derivatives. We pay particular attention to the treatment of noise in the simulation and introduce a statistical testing mechanism to determine when our model has captured the underlying simulation function, excluding the noise.

The mechanism has been successfully implemented in GAMS (the modeling language used by several Air Force installations). We have demonstrated the utility of this approach on small-scale simulations, and are currently developing the codes for improved robustness.

This work is described in the paper numbered 24 in Section 5, and also in the Ph.D. dissertation of Krung Sinapiromsaran, produced with support from the grant In both places, we detail how

simulations are automatically reused in model building and justify several choices made in our experimentation. The strength of this work is to allow standard modeling and optimization tools to be easily and conveniently used to optimize existing simulation systems.

3.2. Models for design of video-on-demand systems

We have developed methods for design of hierarchical systems with new delivery techniques. These systems are by their very nature subject to stochastic inputs, and a variety of queuing models have been developed to analyze them. Our work has shown how to use optimization in critical design decisions. This work was disclosed in late July 1999 to the Wisconsin Alumni Research Foundation (WARF). On 7 August 2000 WARF filed a utility patent application (P00039US) entitled "Method for Caching of Media Files to Reduce Delivery Cost," Derek Eager, Michael Ferris and Mary Vernon (co-inventors)
(see Section 7 below).

3.3. A fault tolerant Condor-PVM mixed integer program solver

Numerous complex optimization problems (such as those in the video-on-demand application mentioned in Section 3.2) require mixed integer programming solvers. Such solvers are required in many Air Force applications as well, since many quantities naturally occur as integer variables (*e.g.* aircraft). Our work has focused on using a meta-computer for solving such problems in conjunction with a branch and bound technique.

We have developed FATCOP 2.0, a new parallel mixed integer program solver that works in an opportunistic computing environment provided by the Condor resource management system. We improved resource utilization over a previous version of FATCOP and added a number of new techniques to exploit heterogeneous resources. We explored several advanced optimization features in the code that are necessary for successful solution of a variety of mixed integer test problems, along with the different mechanisms for their use that are pertinent in our particular computing environment. Over the period June-August 2000, we solved to optimality three problems for the first time. One of these problems, Seymour, has been open for at least 10 years, and took over 1 year CPU time, over 10 million nodes explored, on over 200 machines running under the Condor system. Similarly, two set covering problems known as t0415 and t0416 have been solved to optimality for the first time using vast amounts of computing resources (in comparison, commercial codes for these problems were unable to find feasible solutions after 48 hours of computing time).

This work is described in the papers numbered 3 and 4 in Section 5 and also in the Ph.D. dissertation of Qun Chen. Preliminary discussions have been held with GAMS Development Corporation regarding possible transfer of this technology to commercial application.

3.4. Gamma Knife radiosurgery

The Gamma Knife is a highly specialized treatment unit that provides an advanced stereotactic approach to the treatment of tumors, vascular malformations, and pain disorders within the head. Inside a shielded treatment unit, beams from 201 radioactive sources are focused so that they intersect at the same location in space, resulting in a spherical region of high dose referred to as a shot of radiation. The location and width of the shots can be adjusted using focusing helmets.

By properly combining a set of shots, larger treatment volumes can be successfully treated with the Gamma Knife.

The goal of our project is to automate the treatment planning process. For each patient, an optimization problem is solved to generate a dose distribution that conforms closely to the treatment volume. The variables in the optimization include the number of shots of radiation along with the size, the location, and the weight assigned to each. We formulate such problems using a variety of mathematical programming models, and solve several test and real-patient examples.

This work is described in the papers numbered 26, 32, and 33 in Section 5. Currently, our (medical) co-author is refining the process to use at the University of Maryland Medical School on actual patients.

3.5. Asymptotics and confidence regions for stochastic variational inequalities

Variational inequalities (VI) are devices that model a large variety of equilibrium problems arising in operations research, engineering, economics, and other areas. In previous AFOSR-supported work, we have shown how to extend the original deterministic idea of a VI to incorporate stochastic elements, and how the resulting models may be numerically solved. We have completed development of a comprehensive methodology for producing confidence regions for such computed solutions, based on reformulation of the VI as an equivalent single-valued, nonsmooth equation. The completed work was reported in the Ph.D. dissertation of Mert C. Demir, produced with support from the grant.

3.6. GAMS-MATLAB Interface

An interface was developed between the algebraic modeling language GAMS and the numerical analysis and visualization environment MATLAB, as a first step toward automatic differentiation (AD) of simulation codes. A small application of this interface to optimize a simulation problem using AD was exhibited at the AFOSR program review meeting in Monterey, CA, May 1998. The interface has also been exploited to produce a useful graphics capability that we anticipate can be applied to simulation optimization problems in various ways. This work is described in the paper numbered 11 in Section 5.

3.7. Modeling Language/CONDOR Interface

An interface between a modeling language (GAMS or AMPL) and the multi-workstation management tool CONDOR has been developed and demonstrated. It permits the solution effort for a large, computation-intensive optimization problem to be parceled out to different workstations and automatically moved from one to another according to the current workload on each station. The demonstration was on a problem in supervised learning. This work is described in the paper numbered 20 in Section 5.

3.8. Stochastic Effects in the NPS-RAND Mobility Optimizer (NRMO)

The NRMO model allocates airlift resources for maximum performance against requirements. However, the degree to which the NRMO solution gives optimal guidance for real decisions depends on how well the optimization model represents the real system. A limitation of the original NRMO model is the assumption that no random factors exist in the system. For

example, the deterministic nature of this model results in its fully utilizing the capacity of some airfields, and a minor need for additional repair resources to deal with maintenance problems of transiting aircraft can extend their ground times, thereby starting a cumulative blockage in the system. Such a blockage can severely degrade the intended flow of cargo. The effect of uncertainty can be studied by applying simulation to a deterministic allocation found by NRMO. However, even if the simulation suggests possible severe problems, it does not show how to adjust the deterministic allocation to overcome those problems with the least cost in resources. For that, a revision of the optimization model is needed.

We started an effort to incorporate stochastic effects into NRMO, beginning with modeling stochastic ground times. A preliminary report was issued in late July 1999 and was shared with the authors of NRMO, who kindly provided comments and suggestions. Subsequently, project staff completed and issued the final version of a technical report on incorporating stochastic elements into NRMO. This work is described in the paper numbered 31 in Section 5.

The stochastic version of NRMO should provide increased realism in planning, because it accounts for randomness that is present in the actual system. However, even the deterministic version of NRMO is a large model, and when stochastic features are added the solution time is considerably extended. It would be helpful to have a modeling tool that could provide quick, though perhaps rough, estimates of the effect of different stochastic factors on throughput in an airlift system.

Therefore, in the latter part of the grant period we started a related effort in enhancement of airlift planning through adaptation of methods recently brought into use in manufacturing. These techniques first model the system under consideration as a network of queues, then use recently developed approximation methods to find estimates of lead time and throughput. Such estimates, though not exact, can pinpoint the location of bottlenecks and can indicate how and where additional resources could improve system performance. These methods have already had substantial success in improving the productivity of complex manufacturing operations. We are currently trying to adapt the manufacturing approach to deal with logistical models such as airlift, and intend first to test the methods on some simple models. If they appear to work well, we expect to ask for cooperation from Air Force operational planners so that we can try the modeling methods on problems of concern to the Air Force.

4. Personnel Supported
The following personnel have received salary support from this grant.
- Kristen M. Akey. Ms. Akey completed requirements for the Bachelor of Science – Industrial Engineering in December 1999.
- Mert C. Demir, Research Assistant. Dr. Demir completed requirements for the Ph.D. in Industrial Engineering in December 1999. He resumed duties as a faculty member at Marmara University, Istanbul, Turkey.
- Michael C. Ferris, Professor
- Jeffrey D. Horn, Research Assistant
- Ananth Krishnamurthy, Research Assistant

- Todd S. Munson, Research Assistant. Dr. Munson completed requirements for the Ph.D. in Computer Sciences in July 2000. He accepted a position as a postdoctoral research associate at Argonne National Laboratory, Argonne, IL.
- Antti J. Niemi. Mr. Niemi completed requirements for the Master of Science – Industrial Engineering in December 1999.
- Stephen M. Robinson, Professor
- Krung Sinapiromsaran, Research Assistant. Dr. Sinapiromsaran completed the requirements for the Ph.D. in Computer Sciences in October 2000. He resumed duties as a faculty member at Chulalongkorn University, Bangkok, Thailand.
- Yi-Chun Tsai, Research Assistant
- Meta M. Voelker, Research Assistant

The following personnel also carried out work directly related to this grant, but were supported by other funding.
- Qun Chen, Research Assistant. Dr. Chen completed the requirements for the Ph.D. in Industrial Engineering in August 2000. He accepted a research and development position at Oracle Corporation, Portland, Oregon.

5. Publications

The following paper acknowledging support under the predecessor AFOSR grant was published during the reporting period.
1. G. Gürkan, A. Y. Özge, and S. M. Robinson, Sample-path solution of stochastic variational inequalities, *Mathematical Programming* **84** (1999) 313-333.

The following papers acknowledge support from the present grant. Their status is as indicated.

1. E. J. Anderson and M. C. Ferris, A direct search algorithm for optimization with noisy function evaluations. Mathematical Programming Technical Report 96-11, Computer Sciences Department, University of Wisconsin, Madison, Wisconsin, 1996. SIAM Journal on Optimization, forthcoming.

2. S. C. Billups and M. C. Ferris, Solutions to affine generalized equations using proximal mappings. Mathematics of Operations Research 24 (1999) 219-236.

3. Q. Chen and M. C. Ferris, FATCOP: A fault tolerant Condor-PVM mixed integer program solver. Forthcoming in SIAM Journal on Optimization, 2001.

4. Q. Chen, M. C. Ferris, and J. T. Linderoth, FATCOP 2.0: Advanced features in an opportunistic mixed integer programming solver. Forthcoming in Annals of Operations Research, 2001.

5. J.-C. De Bremaecker and M. C. Ferris, A comparison of two algorithms for solving closed crack problems. Engineering Fracture Mechanics, 66:601-605, 2000.

6. J.-C. De Bremaecker, M. C. Ferris, and D. Ralph, Compressional fractures considered as contact problems and mixed complementarity problems. Engineering Fracture Mechanics 66 (2000) 287-303.

7. W. D. D'Souza, R. R. Meyer, M. C. Ferris, and B. R. Thomadsen, Mixed integer programming models for prostate brachytherapy treatment optimization. Medical Physics 26(6) (1999) 1099.

8. W. D. D'Souza, R. R. Meyer, M. C. Ferris, and B. R. Thomadsen, An iterative sequential mixed-integer approach to automated prostate brachytherapy treatment optimization. Forthcoming in Physics and Medicine in Biology, 2001.

9. D. L. Eager, M. C. Ferris, and M. K. Vernon, Optimized regional caching for on-demand data delivery. In Multimedia Computing and Networking [Proceedings of SPIE, 18% acceptance rate], Vol. 3654, Bellingham, Washington, 1999.

10. D. L. Eager, M. C. Ferris, and M. K. Vernon, Optimized caching in systems with heterogeneous client populations. Performance Evaluation, 42:163-185, 2000.

11. M. C. Ferris, MATLAB and GAMS: Interfacing optimization and visualization software. Mathematical Programming Technical Report 98-19, Computer Sciences Department, University of Wisconsin, Madison, Wisconsin, 1998.

12. M. C. Ferris, R. Fourer, and D. M. Gay, Expressing complementarity problems and communicating them to solvers. SIAM Journal on Optimization 9 (1999) 991-1009.

13. M. C. Ferris and C. Kanzow, Complementarity and related problems: A survey. Forthcoming in: P. M. Pardalos and M. G. C. Resende, eds., Handbook of Applied Optimization. Oxford University Press, 2001.

14. M. C. Ferris, C. Kanzow, and T. S. Munson, Feasible descent algorithms for mixed complementarity problems. Mathematical Programming 86 (1999) 475-497.

15. M. C. Ferris, A. Meeraus, and T. F. Rutherford, Computing Wardropian equilibrium in a complementarity framework. Optimization Methods and Software 10 (1999) 669-686.

16. M. C. Ferris, M. P. Mesnier, and J. Moré, NEOS and Condor: Solving nonlinear optimization problems over the Internet. ACM Transactions on Mathematical Software, 26:1-18, 2000.

17. M. C. Ferris and R. R. Meyer, Models and solution for on-demand data delivery problems. In: P. M. Pardalos, ed., Approximation and Complexity in Numerical Optimization: Continuous and Discrete Problems, Volume 42 of Nonconvex Optimization and its Applications, pages 175-188. Kluwer, Dordrecht, 2000.

18. M. C. Ferris and T. S. Munson, Case studies in complementarity: Improving model formulation. In: M. Théra and R. Tichatschke, eds., Ill--Posed Variational Problems and Regularization Techniques, Volume 477 in Lecture Notes in Economics and Mathematical Systems, pp. 79-98. Springer-Verlag, Berlin, 1999.

19. M. C. Ferris and T. S. Munson, Complementarity problems in GAMS and the PATH solver. Journal of Economic Dynamics and Control 24 (2000) 165-188.

20. M. C. Ferris and T. S. Munson, Modeling languages and Condor: Metacomputing for optimization. Mathematical Programming, 88:487--506, 2000.

21. M. C. Ferris and T. S. Munson, Preprocessing complementarity problems. Proceedings of ICCP'99, forthcoming.

22. M. C. Ferris and T. S. Munson, Interior point methods for massive support vector machines. Data Mining Institute Technical Report 00-05, Computer Sciences Department, University of Wisconsin-Madison, Madison, Wisconsin, 2000. Submitted to SIAM Journal on Optimization.

23. M. C. Ferris, T. S. Munson, and D. Ralph, A homotopy method for mixed complementarity problems based on the PATH solver. In: D. F. Griffiths and G. A. Watson, eds., Numerical Analysis 1999, Research Notes in Mathematics, pp. 143-167. Chapman and Hall, London, 2000.

24. M. C. Ferris, T. S. Munson, and K. Sinapiromsaran, A practical approach to sample-path simulation optimization. In Proceedings of the Winter Simulation Conference, J.A. Joines, R.R. Barton, K. Kang, and P.A. Fishwick (editors), pages 795-804, Omnipress, Orlando, Florida, 2000.

25. M. C. Ferris and A. Ruszczynski, Robust path choice and vehicle guidance in networks with failures. Networks 35 (2000) 181-194.

26. M. C. Ferris and D. M. Shepard, Optimization of gamma knife radiosurgery. In: D.-Z. Du, P. Pardalos, and J. Wang, eds., Discrete Mathematical Problems with Medical Applications, volume 55 of DIMACS Series in Discrete Mathematics and Theoretical Computer Science}, pages 27-44. American Mathematical Society, 2000.

27. M. C. Ferris and K. Sinapiromsaran, Formulating and solving nonlinear programs as mixed complementarity problems. In: V.H. Nguyen, J. J. Strodiot, and P. Tossings, eds., Optimization, Volume 481 in Lecture Notes in Economics and Mathematical Systems, Springer-Verlag, Berlin, 2000.

28. M. C. Ferris and F. Tin-Loi, On the solution of a minimum weight elastoplastic problem involving displacement and complementarity constraints. Computer Methods in Applied Mechanics and Engineering 174 (1999) 107-120.

29. G. Gürkan, A. Yonca Özge, and S. M. Robinson, Solving stochastic optimization problems with stochastic constraints: An application in network design. In: P.A. Farrington, H. B. Nembhard, D. T. Sturrock, and G. W. Evans, eds., Proceedings of the 1999 Winter Simulation Conference, pp. 471-478.

30. T. S. Munson, F. Facchinei, M. C. Ferris, A. Fischer, and C. Kanzow, The semismooth algorithm for large scale complementarity problems. Submitted to INFORMS Journal on Computing.

31. A. Niemi, Stochastic modeling for the NPS/RAND Mobility Optimization Model. Technical Report 2000-1, Department of Industrial Engineering, University of Wisconsin-Madison, August 2000.

32. D. M. Shepard, M. C. Ferris, G. Olivera, and T. R. Mackie, Optimizing the delivery of radiation to cancer patients. SIAM Review 41 (1999) 721-744.

33. D. M. Shepard, M. C. Ferris, R. Ove, and L. Ma, Inverse treatment planning for gamma knife radiosurgery. Medical Physics, 27:12, 2000.

34. F. Tin-Loi and M. C. Ferris, Complementarity problems in engineering and mechanics: Models and solution. In: C. M. Wang, K. H. Lee, and K. K. Ang, eds., Computational Mechanics for the Next Millenium, Volume 2 of Proceedings of APCOM '99, Fourth Asia-Pacific Conference on Computational Mechanics, pp. 1029-1036. Elsevier Science Ltd, 1999.

6. Interactions/Transitions

6.1. Participation/presentations at meetings, conferences, seminars, etc.

The following meeting/conference presentations involved material related to the research program of this grant.

1. INFORMS Computer Sciences Technical Section, Monterey, CA, January 1998 (Robinson). This occurred after the termination date of the predecessor grant and prior to the start date of this grant; it was funded under the pre-award cost provision of the FDP.
2. ARPI Program Review, including AFOSR/NM review meeting, Monterey, CA, May 1998 (Robinson).
3. "Mixed Complementarity Problems: Practical Modeling and Ill-Posedness" (Ferris), Workshop on Ill-Posed Variational Problems and Regularization Techniques, University of Trier, Germany, September 1998.
4. "Environments and Algorithms for Complementarity Problems" (Ferris), Ninth Belgian-French-German Conference on Optimization, Namur, September 1998.
5. "FATCOP"(Ferris), Argonne National Laboratories, October 1998.
6. "Optimization and Equilibrium" (Robinson), Optimization Plenary Lecture, INFORMS Seattle, October 1998.
7. "Tutorial: Complementarity Problems - Applications, Modeling and Solution" (Ferris), INFORMS Seattle, October 1998.

8. "Models and Solution for On-Demand Data Delivery Problems" (Ferris), Conference on Approximation and Complexity in Numerical Optimization: Continuous and Discrete Problems, Gainesville, Florida, March 1999.
9. "Modelling Languages and Condor" (Ferris), 6th SIAM Conference on Optimization, Atlanta, May 1999.
10. "Optimization and Simulation: A Practical Approach" (Ferris and Robinson), AFOSR Program Review Meeting, Blue Mountain Lake, NY, May 1999.
11. "FATCOP: A Progress Review" (Ferris), Argonne National Laboratories, June 1999.
12. "PATH and the Merge Model" (Ferris), International Conference on Complementarity Problems, Madison, Wisconsin, June 1999.
13. "Composition Duality" (Robinson), International Conference on Complementarity Problems, Madison, Wisconsin, June 1999.
14. "Complementarity Problems and Equilibrium Programming" (Ferris), 19th Dundee Numerical Analysis Conference, July 1999.
15. "Metacomputing in optimization" (Ferris), INFORMS Meeting, Philadelphia, November 1999.
16. "FATCOP: A fault tolerant Condor--PVM mixed integer program solver" (Ferris), INFORMS Meeting, Philadelphia, November 1999.
17. "Preprocessing complementarity models" (Ferris), INFORMS Meeting, Philadelphia, November 1999.
18. "Optimization in Gamma Knife radiosurgery" (Ferris), DIMACS, Rutgers University, New Jersey, December 1999.
19. "Scenario analysis in U. S. Army decision making" (Robinson), Mathematisches Forschungsinstitut Oberwolfach, January 2000.
20. "Robust optimization in planning force operations" (Robinson), meeting on "Modeling and Simulation for Operations and Training Program," U.S. Army Research Office and STRICOM, Orlando, FL, February 2000.
21. "Optimization and metacomputing" (Ferris), Condor/Paradyn Meeting, Madison, WI, March 2000.
22. "Sample-path methods in stochastic optimization" (Robinson), Department of Engineering Management and Systems Engineering, The George Washington University, Washington, DC, March 2000.
23. "Modeling and Solving Complementarity Problems" (Ferris), Applied Mathematical Programming and Modelling, London, April 2000.
24. "Optimization in Gamma Knife Radiosurgery" (Ferris), Data Mining Institute Annual Review, Madison, June 2000.
25. "FATCOP: A fault tolerant Condor-PVM mixed integer program solver" (Ferris), 17th International Symposium on Mathematical Programming, Atlanta, August 2000.
26. "Planning under uncertainty: Methods and applications" (Robinson) AFOSR Program Review, Lockheed-Martin Corp., Orlando, FL, September 2000.

In addition to meeting presentations, the principal investigators performed the following meeting organization and supervision services during the period of this grant.

- Session organizer and chair, Fall National Meeting of the Institute for Operations Research and the Management Sciences (INFORMS), Seattle, WA, October 1998 (Robinson).

- Chairman of organizing committee, "ICCP99: International Conference on Complementarity Problems: 35 years later," held in Madison, Wisconsin, June 9 - 12, 1999 (Ferris).
- Member of the Organizing Committee, 6th SIAM Meeting on Optimization, held in Atlanta, GA, May 1999 (Ferris).

6.2. Consultative and advisory functions to other laboratories and agencies

- Invited participation in the Mathematical and Computer Sciences Division 1998 Triennial Investment Strategy Meeting at the U.S. Army Research Office in March 1998 (Robinson).
- Two days' service as a panel member for the Knowledge and Distributed Intelligence initiative of the National Science Foundation, Washington, DC, March 1999 (Robinson).
- Two days' service as a panel member for the Information Technology Research initiative of the National Science Foundation, San Francisco, CA, May 2000 (Robinson).

6.3. Transitions

The PATH solver for mixed complementarity problems, whose development was partially funded via previous AFOSR grants, is now an integral part of the GAMS modeling system. Negotiations are currently in progress between one of the PIs and GAMS Development Corporation to transfer the GAMS/MATLAB interface and the GAMS/CONDOR technology in a similar manner. Version 4.4 of the PATH solver was released during the period of this grant. This version includes a preprocessor developed with support from this grant, some of whose features are described in the paper numbered 21 in Section 5. Also, a student version of PATH was made available via anonymous FTP.

We had previously developed an interface between the GAMS algebraic modeling language and the MATLAB visualization and numerical computation environment, and have been using this in the AFOSR research program. We have now made this interface publicly available via anonymous ftp. GAMS Development Corp. (developers of GAMS) has put this software on their web page (http://www.gams.de/5download/tools.htm). It is being used by a variety of researchers worldwide. Installation and use of this interface are detailed in the paper numbered 11 in Section 5.

The MATLAB/GAMS interface, described in the paper numbered 11 in Section 5, was made publicly available via anonymous FTP.

A graduate student from the project, Qun Chen, spent a period of two months at the GAMS Development Corporation, showing how the Condor system can be used on a cluster of workstations to solve hard mixed integer programs using FATCOP, and how to run models in parallel on Condor directly from a GAMS program.

A co-author, David Shepard, is refining our planning system on the Gamma Knife to use in practice at the University of Maryland Medical School on actual patient cases.

7. New discoveries, inventions, or patent disclosures

In late July 1999, M. C. Ferris and M. Vernon (University of Wisconsin-Madison), D. Eager (University of Saskatchewan), and J. Zahorjan (University of Washington), disclosed their recent multimedia delivery and caching results to the Wisconsin Alumni Research Foundation

(WARF). WARF is an independent foundation that holds and administers patent rights for many discoveries made by Madison faculty members, generating a stream of income that is then passed back to the University in the form of funds for the support of further research.

In August 1999 WARF filed a provisional patent application covering this work. The provisional application serves as a placeholder for one or more actual patent applications, which may be made during the year following its filing. If actual patent applications are filed during that time period, each such actual patent application will be treated as if it were filed on the date that the provisional application was filed.

On 7 August 2000 WARF filed a utility patent application (P00039US) entitled "Method for Caching of Media Files to Reduce Delivery Cost," Derek Eager, Michael Ferris and Mary Vernon (co-inventors). Ferris' work on this invention was supported by the AFOSR grant.

8. Honors/Awards

During the period of this grant Ferris received the Vilas Associate Award of the University of Wisconsin-Madison, for the period 1999-2001.
Former awards (lifetime achievement honors) of the principal investigators include:
- Doctor *honoris causa,* University of Zürich, Switzerland, April 1996 (Robinson)
- George B. Dantzig Prize, Mathematical Programming Society (MPS) and the Society for Industrial and Applied Mathematics (SIAM), July 1997 (Robinson)
- Beale-Orchard-Hays Prize, Mathematical Programming Society (MPS), August 1997 (Ferris)